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(54) A RADIO NAVIGATIONAL SYSTEM

(71) We, LIGHTVALE ELECTRICS LIMITED, a British Company, of Mullion Cottage, Bar Road, Helford Passage, Falmouth, Cornwall, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to radio navigational systems of the type in which a position line, for instance for a ship, is established by measurement of the difference in the times of travel to the ship or other craft of two radio signals produced by respective radio transmitters. It will be understood that the signals are received and the measurement made using a radio receiver carried by the craft. If a position fix is required, a second position line is established using two other transmitters, or a third transmitter in conjunction with one of the original two transmitters. The point of intersection of the two position lines then gives the position fix for the craft.

Systems of this type include the "Gee" system and the "Loran" system. Both are pulse systems and the method of measurement necessitates visual display of the pulses on an oscilloscope screen and subsequent alignment so as accurately to measure the time interval between their receipt. A more recent system known as the "Loran C" system differs only in that a lower frequency signal is used and that a number of pulses are transmitted instead of only one. Although Loran systems are in use, they have a number of drawbacks. In particular the receiver is complicated and expensive and also necessitates considerable skill on the part of the operator. This renders it generally unsuitable for small marine craft. Moreover, for inshore work such systems are usually not sufficiently accurate. Another drawback is that a wide frequency bandwidth is utilised necessitating accommodation of groups of transmitters on one frequency but at different pulse repetition rates. This limits the number of groups of transmitters and complicates reception.

Another well-known system is that known by the Registered Trade Mark "Decca". This system operates by measuring the phase difference between continuous radio signals transmitted by respective transmitters. Complicated methods have to be used to prevent ambiguity of position which would otherwise occur due to the presence of the large number of wavelengths between the transmitters. Although widely used as it is extremely accurate, this system is even more expensive than the Loran systems. The smaller less bulky version as used in aircraft would be suitable for small marine craft if it was not so expensive.

According to the present invention, in a radio navigational system of this type, that is to say for establishing a position line by measurement of the difference in the times of travel of two radio signals produced by respective radio transmitters, the signals each have a frequency which repetitively increases from and decreases to, a basic frequency, at equal repetition rates, in such a manner that the instantaneous frequency difference between the transmitted signals has at any instant a predetermined value, the two basic frequencies being different. For instance the frequencies may repetitively increase and decrease in the manner of respective saw-tooth waves. The receiver is tuned to receive both signals and, by causing both signals to beat with one another to produce a heterodyne frequency, provides an indication of the difference in the times of receipt of the signals, i.e. the difference in the times of travel, and thus of the difference between the distances from the receiver to each transmitter. Accordingly this establishes a hyperbolic position line. Repetition of the procedure using another pair or a third transmitter establishes a second hyperbolic position line and the resulting point of intersection gives a position fix.

In Marconi's British Patent Specification No. 889,843 a system is disclosed in which two different carrier frequencies are amplitude modulated by signals having the same

sub-carrier frequency but frequency-modulated by a common modulating frequency but with phase displacement, so that the information carried by the two carriers consists of two signals which are the same except for a difference in phase.

The present invention is distinguished from Marconi in that the 'basic frequency', which is 'the frequency which is frequency modulated to provide the instantaneous frequency difference', is a different frequency for the two transmitters. In Marconi the sub-carrier frequency which is frequency modulated to provide the instantaneous frequency difference is the same for the two transmitters.

This system has a number of important advantages over existing systems. In particular the receivers can be simple and hence reliable. They can be cheaply produced and moreover since they may also be simple to operate, they are admirably suited for use in small marine craft as well as in aircraft. They may be portable for instance and run off self-contained batteries. Although the simplest form of receiver may be less accurate than a "Decca" (R.T.M.) receiver, sufficient accuracy for small marine craft can be obtained. More sophisticated receivers can be provided where accuracy is more important than expense and size.

Another particularly important advantage of the system is that only a very small frequency bandwidth is required. In this context, existing radio direction finding (R.D.F.) beacons can be used as the transmitters without interfering with their existing purpose and with only a small or no increase in their frequency bandwidth. It will be appreciated that the use of existing transmitters reduces the cost of setting up the system while the use of what are basically existing transmission frequencies is desirable due to the already overcrowded frequency spectrum.

The principle on which the invention is based is best understood by considering as an example a receiver which measures and provides an indication of the heterodyne frequency, for instance on a scale calibrated in arbitrary units corresponding to similarly designated position lines on the relevant chart. This frequency is dependent on the difference between the frequencies of the two signals received by the receiver. For instance if one transmitter was to produce a signal having a steady frequency of 100 KHz. and the other 99.2 KHz., the heterodyne frequency measured by the receiver as a result of these two signals beating together would be 800 Hz. From this it can be seen that if the frequencies of both signals are increased or reduced simultaneously and at the same rate so as to maintain the same frequency difference between the transmitted signals, i.e. 800 Hz., the measured heterodyne frequency remains 800 Hz. provided that the signals are received simultaneously. As, however, electromagnetic radiation travels at a finite speed (186,000 miles/sec.) the signals, although transmitted simultaneously, are only received simultaneously if the receiver is equidistant from the two transmitters. If the receiver is nearer one transmitter than the other, the difference in frequency of the received signals, i.e. the heterodyne frequency, is either greater than or less than the difference in frequency of the transmitted signals, i.e. 800 Hz., due to the difference between the periods taken by the signals to reach the receiver. Hence, from the value of the heterodyne frequency measured by the receiver, a position line for the craft may be established.

Reference to Figures 1*a* and 1*b* of the accompanying drawings exemplifies the foregoing. In Figure 1*a* a transmitter located at position A commences transmitting a signal of a frequency of 100 KHz. which increases linearly over a period of 0.005 seconds to a frequency of 100.5 KHz. at which instant it instantaneously drops to 100 KHz. and then repeats the cycle, as designated by "A at A" in Figure 1*b*. Simultaneously with the transmitter at A starting to transmit, a second transmitter located at position B commences transmitting a signal of a frequency of 99.2 KHz. which increases linearly over the same period of time to 99.7 KHz. at which instant it instantaneously drops to 99.2 KHz. and then again repeats the cycle. This signal is designated "B at B". The two transmitters are considered as located 186 miles apart for ease of calculation. A receiver lying on a line CD equidistant from the transmitters receives over each successive period of 0.005 second two signals differing in frequency by 800 Hz. However, if the receiver instead of being equidistant from the transmitters, is located nearer to the transmitter A than to the transmitter B, the earlier receipt of the signal from the transmitter A and the later receipt of the signal from the transmitter B means that the starts of the two signals at the beginning of each period is not received simultaneously. Instead the start of the signal from the transmitter A arrives first followed by that from the transmitter B. By the time the start of the latter signal is received, the frequency of the former signal has risen above its starting value of 100 KHz. Accordingly the difference in frequencies at the receiver is no longer 800 Hz. but a greater value dependent on the difference between the distances from the receiver to the two transmitters. The maximum value is 900 Hz. which occurs when the receiver is located at the transmitter A.

For instance the frequency difference may be 850 Hz. Calculation shows that this corresponds to the receiver being 93 miles nearer to the transmitter A than to the transmitter B. Compared with the equidistant position, the start of the signal from transmitter A is 0.00025 seconds earlier and that from transmitter B 0.00025 seconds later giving a total difference in start time of 0.0005 seconds which corresponds to 850 Hz. Accordingly the heterodyne frequency of 850 Hz. indicated by the receiver shows that the receiver is located on a line which is 93 miles nearer to the transmitter A than it is to the transmitter B and it follows that this line is a hyperbola. Naturally if the heterodyne frequency is less than 800 Hz., the receiver must be nearer to the transmitter B than to the transmitter A. The minimum frequency is 700 Hz. which occurs when the receiver is located at the transmitter B. As already mentioned, at the end of each 0.005 second period, the frequencies of the two signals return instantaneously to their starting values from which they again linearly increase. Accordingly each transmitter produces a signal which repetitively sweeps through a frequency bandwidth of 500 Hz. at a repetition frequency of 200 Hz.

It can be seen from this example that the position line of the receiver is indicated by a particular heterodyne frequency. Hyperbolic position lines, as shown in Figure 1*a*, corresponding to particular heterodyne frequencies may be over-printed on charts for various transmitters.

In practice owing to the different signal strengths of the received signals dependent principally upon the relative distances of the transmitters from the receiver, it is in most cases desirable to receive the signals separately so that they can subsequently be brought for instance by A.V.C. to a closer level to one another. This can be carried out if one of the following conditions exists:—

A. One frequency is approximately a multiple of the other (e.g. approximately 50 KHz. and 100 KHz.).
B. The frequencies have a common sub multiple (e.g. approximately 100 KHz. and 150 KHz. with a common sub multiple at 50 KHz.).
C. The frequencies have a common multiple (e.g. approximately 100 KHz. and 80 KHz. having a common multiple of 400 KHz.).

In the above cases, frequency multiplying or dividing circuits may be employed to obtain the necessary heterodyne frequency.

However, it is often not convenient to use frequencies related in any of these ways. Under these circumstances, it is usually necessary to employ superheterodyne circuits in the receiver to convert the frequencies to a common frequency. In such a receiver the local oscillator frequencies must be accurate, the degree of accuracy depending mainly on any frequency multiplication which may be carried out in the receiver, as is discussed later. Otherwise an incorrect heterodyne frequency will be produced. In addition any drift in either of the local oscillator frequencies results in the heterodyne frequency changing and thus an incorrect position line. This can be avoided by using local oscillators having extremely accurate and stable frequency characteristics. However, this renders the receiver expensive.

The preferred way of overcoming this problem is for each transmitter to produce a signal having a frequency which, in addition to repetitively increasing and decreasing as already described, over other periods has a constant frequency different from that of the other signal. In other words, the frequencies over one period are both constant and over another period repetitively increase and decrease, the periods for example each having a duration of half a second. A receiver for use in such a system includes two superheterodyne radio receiving channels, an adjustable delay arrangement for adjustably delaying the signal from one of the channels, a mixer for causing the signal from the delay arrangement and from the other channel to beat with one another to produce a heterodyne frequency, and an indicating arrangement having a first indicator for indicating whether the heterodyne frequency remains constant and a second indicator controlled by the delay arrangement for providing an indication of the delay when the heterodyne frequency remains constant. The receiver is operated by adjusting the delay arrangement until the first indicator, preferably a loudspeaker, indicates that the heterodyne frequency remains constant from period to period whereupon the second indicator is then read. When so adjusted, the heterodyne frequency produced from the repetitively increasing and decreasing frequencies is equal to the heterodyne frequency produced from the constant frequencies. The latter heterodyne frequency is unaffected by the position of the receiver in relation to the transmitters and hence serves as a reference for the other heterodyne frequency which, it will be understood, is made equal to it by delaying one of the signals in the receiver. The magnitude of the delay required for equality, as represented by the indication given by the second indicator, is indicative of the position line for the receiver. It is particularly important to note that since the frequencies are being compared with one another, any variation in either of the local oscillator

frequencies affects the heterodyne frequencies produced as a result of the constant frequency and increasing and decreasing frequency portions of the signals to an equal extent. Thus such variations are relatively unimportant. Accordingly cheap local oscillators may be used in such a system.

Another problem is that of obtaining accurate position information while utilising only a narrow frequency bandwidth. This may be overcome by employing separate frequency multiplication circuits in the receiver, as indicated previously, for multiplying the frequencies of the two signals prior to beating the signals together. This results in a greater heterodyne frequency range for a given distance and bandwidth, that is the width of the frequency band through which the signals repetitively sweep.

The ideal radio navigational system to be introduced into an already congested frequency spectrum would be one requiring very little or no additional frequency space. A particularly important feature of the invention is that by using existing transmitters such as marine and aircraft radio beacons and Consol beacons already existing in this and various other countries for radio direction finding, this can be achieved.

In the case of marine beacons around the coast of this country, a signal of constant frequency between 285 and 315 KHz. is produced for a period of 25 seconds, in most instances once every six minutes. This 25 second period forms part of a one minute transmission period also including identification signals identifying the beacon. According to the form of the system now to be described, at least two of these beacons are modified so that over alternate half seconds periods within some part of the minute period, for instance within the 25 second period, they transmit respectively their normal non F.M. (frequency modulated) signals followed by the repetitively increasing and decreasing frequency signals, subsequently referred to as the F.M. signals. This form of transmission will now be described by way of example with reference to Figures 2*a* and 2*b* of the accompanying drawings.

Each of the two beacons, which for ease of calculation are assumed to be 186 miles apart (in practice the beacons are in most cases closer than this), transmits half second periods of the F.M. signal and the non F.M. signal alternately. Each signal is generated at its respective beacon, one of which will be referred to as the "master" beacon since the signal transmitted by the other is synchronised to it. This other beacon is therefore referred to as the "slave" beacon.

In the case of the master beacon, following transmission of an identification signal a non F.M. signal of 300 KHz. is transmitted for half a second after which the F.M. signal is transmitted for half a second followed by the non F.M. signal again and so on. The F.M. signal starts with a frequency of 299.9 KHz. and rises linearly over a period of 0.005 seconds to 300.1 KHz., after which the frequency instantaneously drops to 299.9 KHz. and repeats the linear increase. Thus the F.M. signal has a repetition frequency of 200 Hz. For purposes which will become apparent, the slave beacon signal is delayed in comparison with the signal from the master beacon. Since the two beacons are spaced apart by 186 miles, a convenient delay to adopt is 0.001 second. In a similar manner to the master beacon following transmission of an identification signal the slave beacon transmits a non F.M. signal of 308 KHz. for a period of half a second and then transmits the F.M. signal over the next half second period after which the non F.M. signal is transmitted for half a second, and so on. The frequency of the F.M. signal increases from 307.9 KHz. in a linear manner to 308.1 KHz. over a period of 0.005 second. The frequency then decreases instantaneously to 307.9 KHz. after which the linear increase is repeated.

Reference should now be made to Figure 2*a* in which the receiver is shown schematically. It includes two channels, namely a master channel for receiving the signals from the master beacon and a slave channel for receiving the signals from the slave beacon. Each channel includes a respective superheterodyne receiver unit. That in the master channel has one or more R.F. stages 1, a mixer 2, a crystal controlled oscillator 3, and an I.F. stage 4. That in the slave channel is similar having one or more R.F. stages 5, a mixer 6, a crystal controlled oscillator 7, and an I.F. stage 8. Each receiver is provided with automatic gain control so that it can receive a wide range of signal strengths without manual adjustment. The signal from the receiver unit in the master channel is applied to a continuously variable ultrasonic delay line 9. The delay which this imparts to the signal can be adjusted by a delay adjustment 10 having a calibrated dial on which the delay is indicated. The delayed signal is subsequently applied to a frequency multiplying circuit 11 where the frequency is multiplied by thirty two times. The signal from the receiver unit in the slave channel is applied direct to a similar frequency multiplying circuit 12 where the frequency is also multiplied 32 times. Both signals are then applied to a mixer 13 in which they beat with one another to produce a heterodyne frequency equal to the difference between their frequencies. This heterodyne frequency is applied to an A.F. amplifier 14 where it is amplified and applied to a loudspeaker 15

and to a frequency meter 16. The pointer of the latter indicates a special mark in response to a predetermined frequency, in fact 1.5 KHz. as explained later.

The receiver is operated as follows. Following tuning and receipt of the indentification signals, if the note produced by the loudspeaker 15 as a result of the alternate F.M. and non F.M. signals has two different audible frequencies over successive half second periods, or if the pointer on the meter 16 moves between two different positions during alternate half second periods, the delay adjustment 10 is adjusted until a continuous note is given and the meter pointer remains stationary on the mark. With the receiver so adjusted, the difference in the times of receipt of the two signals from the transmitters is indicated on the calibrated dial of the delay adjustment 10. It will be appreciated that the dial may be calibrated in arbitrary units corresponding to similarly designated position lines on the relevant chart. Thus, from the reading on the dial, the position line for the receiver is established.

It will be assumed that the receiver unit in the master channel has an intermediate frequency of 465 KHz. Since the frequency of the non F.M. signal transmitted by the master beacon is 300 KHz., the oscillator 3 is arranged to have a frequency of 165 KHz. A suitable frequency for the signal produced by the loudspeaker 15 is 1.5 KHz. It will be appreciated that this is a heterodyne frequency resulting from the mixing or beating together of the two signals from the frequency multiplying circuit 11 and 12. With an intermediate frequency of 465 KHz. in the master channel and a heterodyne frequency of 1.5 KHz. after frequency multiplication by 32, it can be shown that the intermediate frequency of the signal in the slave channel must be 464.953125 KHz. Since the slave beacon produces a non F.M. signal having a frequency of 308 KHz., the oscillator 7 should have a frequency of 156.953125 KHz.

Reference should now be made to Figure 2*b* which shows the variation with time of the intermediate frequencies over the end of a non F.M. signal period and the beginning of a F.M. signal period. It can be seen that the I.F. of the non F.M. signal from the master beacon is 465.000000 KHz. while the I.F. of the non F.M. signal from the slave beacon is 464.953125 KHz. At an instant indicated as time zero, the signal from the master beacon instantaneously commences its half second F.M. period, dropping to a frequency of 464.900000 KHz. and over the next 0.005 second period linearly increasing to a frequency of 465.100000 KHz. At the end of this period, it instantaneously drops to 464.900000 KHz. and subsequently repeats the linear increase and so on until the end of the half second period. The signal from the slave beacon remains at its non F.M. frequency until a period of 0.001 seconds has elapsed from time zero. It then commences its half second F.M. period by decreasing to a frequency of 464.853125 KHz. and over the next 0.005 seconds increasingly linearly to a frequency of 465.053125 KHz. whereupon it decreases instantaneously and repeats the linear increase and so on until the end of the half second period. At the end of both half second periods, the non F.M. signals are transmitted for further half second periods, followed by the F.M. signals and so on.

When the non F.M. signals are being transmitted, the heterodyne frequency produced by the loudspeaker is (465.000000—464.953125 KHz.)$\times$32=1.5 KHz. During the following half second period, the frequency of the heterodyne signal depends on the position of the receiver relative to the two transmitters. For example, if the receiver is at the master beacon, the frequency of the signal received from this beacon at any instant is given by the line designated "master at master beacons" while the frequency of the signal received from the slave beacon at any instant is given by the line designated "slave at master beacon." It can be seen that the instantaneous frequency difference at the receiver is the vertical difference between these two lines which is 126.875 Hz. If the receiver is located at the slave beacon, it can be seen that for the same reasons, the frequency difference is 46.875 Hz. Between these two positions, the frequency difference varies between 46.875 and 126.875 Hz. After multiplication by 32 in the frequency multiplying circuits, the total range of frequency difference is 2560 Hz. This corresponds to the 186 miles between the transmitters and accordingly the frequency difference varies by approximately 14 Hz. per mile along a straight line joining the beacons.

It can be seen from this that the note produced by the loudspeaker 15 varies between 1.50 KHz. and 4.06 KHz. depending on the position of the receiver and on the delay adjustment 10. As already explained, the receiver is adjusted by adjustment of the delay adjustment until what is to the ear a continuous note, i.e. over successive half-second periods and which has a frequency of 1.5 KHz., is produced by the loudspeaker 15. Reference to Figure 2*b* shows how delaying the signal in the master channel by up to 0.002 seconds enables this note to be produced at any position of the receiver between the two beacons. It can be seen that if it is necessary to delay the signal from the master beacon by the maximum amount, the receiver must be located at the

master beacon while if it is not necessary to delay the signal at all, the receiver must be located at the slave beacon.

As already explained, one mile along a straight line joining the two beacons is represented by a change of frequency of about 14 Hz. Most people can discern a difference in frequency of less than half this amount and hence using the loudspeaker, a position line can be established to within less than half of one mile. By means of the meter 16, it is possible to improve on this since the meter can be arranged to indicate smal frequency differences in this region, that is approximately 1.5 KHz.

The preceding description has explained how a position line can be established by obtaining an indication of the value of the heterodyne frequency, either by directly measuring it or preferably by measuring the delay to one of the received signals necessary to give the heterodyne frequency a predetermined value. Another form of the system will now be described. In this the frequency sweeps of the transmitted signals, that is the repetitive frequency increases and decreases, have their phase displacement slowly and cyclically altered, preferably over a lengthy period for example the 25 second period previously mentioned, also in such a manner that the instantaneous frequency difference between the transmitted signals has at any instant a predetermined value. It can be seen that at the receiver the frequency sweeps together with the slow alteration of phasing of the sweeps causes the heterodyne frequency to vary and at any instant is dependent on the position of the receiver at that instant and the difference in the phasing of the two signals at that instant. Prior to the start of this alteration of phasing, short constant frequency signals to produce a constant frequency heterodyne signal for use as a reference signal may be transmitted. The time which elapses between the end of this reference signal and the production of a predetermined heterodyne frequency is dependent on the position of the receiver. A timer may be provided to time this period and may conveniently include a trigger circuit or relay which is set in operation when the reference signal ceases and which is stopped by the production of the predetermined heterodyne frequency. A hyperbolic position line can thus be established from the reading on the timer.

The presence of a timer in the receiver is naturally an added complication. This may be eliminated resulting in a simpler and cheaper receiver if the transmitter signals are modified in a manner similar to that already described with reference to Figures 2*a* and 2*b*, that is by making each signal have over alternate periods a constant frequency different from that of the other signal and the varying phase displacement just described. The constant frequencies produce a constant frequency heterodyne frequency. The receiver instead of including a timer includes an indicator, preferably a loudspeaker, for indicating any frequency difference in the heterodyne frequency produced in successive periods. The system is arranged to operate such that the number of discrete signals produced by the indicator from a reference instant until the frequency difference is substantially zero gives the necessary information for the position line.

This form of system is more easily understood by considering an example, for which purpose reference should be made to Figure 3*a* of the accompanying drawings. Consider each of two transmitters to transmit a signal having a constant frequency, referred to as the non F.M. signal, over alternate half-second periods and over the intermediate half-second periods to transmit the F.M. signal. In the case of the latter, the time lag between the start of the F.M. sweep of the signal from one transmitter and the start of the F.M. sweep of the signal from the other transmitter is decreased by an equal step each half-second F.M. signal period. In the receiver, which has a loudspeaker as the indicator, a heterodyne frequency audio signal shown in Figure 3*a* as having a frequency of 1.50 KHz. is produced for half a second from the non F.M. signals followed by a half second heterodyne frequency audio signal from the F.M. signals and so on alternately. The latter signal has a different audio note than that from the non F.M. signals and varies in 0.05 KHz. steps from a frequency higher than 1.50 KHz. over alternate half second periods due to the change in phasing of the frequency sweeps until the audio notes in successive periods become equal or similar to one another, after which the audio note frequency decreases below 1.50 KHz. The number of half second periods of varying heterodyne frequency which elapse from the beginning of the phase displacement cycle to this instant, shown as five in the Figure, are counted by the operator by listening to the notes produced by the loudspeaker. By arranging for a sufficient number, for instance fifty two,, to elapse over a sufficient period of time, for instance fifty two seconds, a reasonably accurate indication of the position line is obtained. The greater the number of steps and the smaller they are, the shorter is the distance represented by each step and the greater the accuracy.

In order to assist in distinguishing between the different heterodyne frequencies and to give improved accuracy, a frequency meter responding to the heterodyne frequency may be employed in addition to or instead of the loudspeaker. The meter

pointer alternates between the F.M. signal frequency and the non F.M. signal frequency. Observation of this indicates when the heterodyne frequencies are equal or similar to one another since when this occurs the pointer reaches a position during an F.M. signal period equal to or just beyond respectively, that of a non F.M. period. As with the loudspeaker the number of counts to reach this is noted. Moreover the degree by which the pointer exceeds the non F.M. position in this F.M. period represents the fraction of the count above the total number of counts. Measurement of this fraction establishes the position line with increased accuracy.

In the form of system described with reference to Figure 3*a*, measurement of the fraction may be difficult and inaccurate. Moreover if the transmitters are R.D.F. beacons, the transmission time available may be relatively short thus restricting the possible number of counts. These difficulties may be overcome by improving on the method of estimating the fractional part of the count. For this purpose the heterodyne frequency produced as a result of the non F.M. signals is arranged to alternate between two different frequencies separated by a frequency difference equal to the frequency step in the heterodyne frequency between successive periods of the F.M. signals. The receiver again includes a meter which indicates the fraction of the heterodyne frequency step occurring after the last count. A system operating in this way will now be described by way of example with reference to Figures 3*b* and 3*c* of the accompanying drawings.

It should be remembered that the system exemplified by these two Figures is fundamentally similar to that described with reference to Figure 3*a*. However, the constant frequency heterodyne frequency alternates between 1.45 KHz. and 1.50 KHz. The frequency difference between these frequencies is 0.05 KHz. which is equal to the frequency steps in the heterodyne frequency produced by the F.M. signals. As just mentioned, the receiver includes a frequency meter which is schematically illustrated in Figure 3*c*. The position A on the scale is shown as 1.0 and is the reading indicated by the meter pointer in response to a frequency of 1.50 KHz. The position B on the scale is shown as 0.0 and is the reading indicated by the meter pointer in response to a frequency of 1.45 KHz. The scale is linearly calibrated in ten divisions from 0 to 1.0 as shown.

While operating the receiver, it may be necessary to adjust one of the local oscillators so that the meter pointer indicates 1.0 during the 1.5 KHz. heterodyne frequency period and to adjust the sensitivity of the meter to read 0.0 during the 1.45 KHz period. The receiver is then operated in the manner described with reference to Figure 3*a*, that is the number of half second periods of varying heterodyne frequency which elapse from the beginning of the F.M. signals are counted. During this time the meter pointer moves in steps between an off-scale position to the left of A corresponding to the F.M. signals, then to the position B corresponding to the 1.45 KHz. signals, then again to an off-scale position, then to A corresponding to the 1.5 KHz. signals. Eventually during an F.M. period it enters part of the scale to the left of the calibration portion and finally enters the calibrated scale between A and B, this corresponding to the half-second period C in Figure 3*b*, and gives a reading on the scale as shown at C in Figure 3*c*. The number of varying heterodyne frequency periods at this instant is an indication of the position line, as described with reference to Figure 3*a*. The reading indicated by the pointer on the calibrated scale during this half second period shows the fraction of one of these periods. This fraction which is 0.5 as shown in Figure 3*b* and 3*c* is thus added to the count thus making it 5.5 in the example.

A receiver operating in the way just described may be very simple indeed and consist of no more than the receiver shown in Figure 2*a* without the delay line and the delay adjustment but with a modified frequency meter as just described. Such a receiver has the very great advantage that approximate positions can be obtained without any very great care merely by counting the audio signals. More accurate positions can be obtained by the use of the meter as described. The most significant advantage is the sheer simplicity of the receiver which requires no calibration whatsoever. All the required accuracies are produced by the transmitters. It is estimated that such receivers may be sold for a sum not exceeding £75.

The design of a system in accordance with the invention is dependent upon many factors, a number of which are listed below:

1) The frequencies of the signals produced by the transmitters.
2) The difference in frequency of the signals produced by the transmitters.
3) The frequency bandwidth (alteration of frequency during transmission) of each transmitter.
4) The repetition frequency of the frequency variation of the transmitters.
5) The wave-form of the frequency variation (saw tooth, triangular etc.) for each transmitter (they may not be similar).
6) The time interval (if any) between the start of a cycle of frequency vari-

ation of one transmitter and that of the other.

7) The distance between transmitters.
8) Whether a time sharing system for different pairs of transmitters is employed (dependent upon some of the above).
9) Whether simultaneous operation of more than one pair of transmitters is used to give simultaneous but different heterodyne frequencies.
10) Whether any one transmitter is paired with more than one other transmitter.
11) Whether the system operates with more than one set of variables as set out above, so as to give fine and coarse accuracies.
12) Whether any of the above factors (1) to (6) are altered during transmission.

It is possible (particularly for high radio frequencies) to modulate the radio frequency (which in this instance may be of any frequency provided it is many times higher than the modulation frequency) at the frequencies suggested in the examples given. If at the receiver the radio frequencies received are rectified or detected in the conventional manner as for reception of modulated radio frequencies, then one is again in possession of the incoming frequencies as indicated in the examples given. These signals may then be used in exactly the same way as described for the received signals in the examples.

As already indicated, a coarse/fine method of position finding may be employed, the system first operating with a low repetition frequency giving the position with coarse accuracy and subsequently with fine accuracy using a higher repetition frequency. In general the heterodyne frequencies should be at least five times the repetition frequency since otherwise it is difficult to measure the heterodyne frequency.

Generation of the transmitter signals may be mechanical. A disc having holes or slots equal to the number of cycles to be transmitted and with appropriate spacing between these holes or slots may be rotated so that a beam of light is projected through each hole to a photoelectric cell. The signal from this may be applied to an amplifier, the signals for transmission being produced in this way. A very high degree of accuracy in the speed of rotation may be obtained by using a synchronous driving motor fed from an accurately controlled frequency derived (after suitable frequency division) from a crystal. This produces both accuracies of repetition and transmitter frequencies. The actual frequencies and change of frequency are controlled by the pitch of the holes.

A preferable method of generation of the transmitter signals is by entirely electronic means. A very accurate F.M. signal centred on say 2 KHz. is mixed with the transmitter signal less than 2 KHz. The result contains signals of the required frequency which may be separated out by filtering. The generation of the 2 KHz. F.M. signal may be achieved by a conventional voltage controlled variable frequency oscillator driven by a voltage having a saw-tooth wave-form.

Initial and periodic synchronisation of the signals may be achieved either by the use of an independent transmission taking place for example once per day, so as to synchronise (or check the synchronisation and correct same) the required relative commencements of the two wave-forms. Maintenance of synchronisation during the intervening period can satisfactorily be achieved merely by the use of high accuracy frequency standards. A variation of not exceeding two parts in 10^8 per day can now be achieved at no very great cost.

An alternative method of obtaining initial synchronisation is to receive the signal transmitted by one transmitter and adjust the phasing of the other signal until such time as the correct position signal is received, for example at or near to the second transmitter. A similar method may be used to check the accuracy of synchronisation and the quality of the signals at any time.

WHAT WE CLAIM IS:—

1. A radio navigational system for establishing a position line, comprising two radio transmitters producing respective radio signals each having a frequency which repetitively increases from and decreases to, a basic frequency at equal repetition rates in such a manner that the instantaneous frequency difference between the transmitted signals has at any instant a predetermined value, the two basic frequencies being different, and a radio receiver tuned to receive both signals and which, by causing both signals to beat with one another to produce a heterodyne frequency, provides therefrom an indication of the difference in the times of travel of the two signals and thereby of the position line.

2. A radio navigational system for establishing a position line, comprising two radio transmitters producing respective radio signals each of which, over alternate periods, has a constant frequency different from that of the other signal and a frequency which repetitively increases and decreases in such a manner that the instantaneous frequency difference between the transmitted signals has at any instant a predetermined value, the frequencies of increase and decrease being the same for the two signals, and a radio receiver including two superhetero-

dyne radio receiving channels each receiving one of the signals, an adjustable delay arrangement by which one of the two received signals is delayed, a mixer causing the delayed and the other signal to beat with one another to produce a heterodyne frequency, and an indicating arrangement having a first indicator indicating whether the heterodyne frequency remains constant from period to period and a second indicator controlled by the delay arrangement and which, when the heterodyne frequency remains constant from period to period, provides an indication of the difference in the times of travel of the two signals and thereby of the position line.

3. A radio navigational system according to claim 2 in which the first indicator is an electroacoustic transducer operating in response to the heterodyne frequency.

4. A radio navigational system according to claim 2 or 3 in which the adjustable delay arrangement includes an ultrasonic delay line.

5. A radio navigational system according to claim 4 in which the receiver is substantially as described with reference to and as illustrated in Figure 2*a* of the accompanying drawings.

6. A radio navigational system for establishing a position line, substantially as described with reference to and as illustrated in Figures 2*a* and 2*b* of the accompanying drawings.

7. A radio navigational system for establishing a position line, comprising two radio transmitters producing respective radio signals having different basic frequencies which repetitively increase and decrease at the same frequency in respective frequency sweeps while simultaneously the phase displacement between the sweeps is slowly and cyclically altered, in such a manner that the instantaneous frequency difference between the transmitted signals has at any instant a predetermined value, and a radio receiver tuned to receive both signals and which, by causing both signals to beat with one another to produce a heterodyne frequency, provides therefrom an indication of the difference in the times of travel of the two signals and thereby of the position line.

8. A radio navigational system for establishing a position line, comprising two radio transmitters producing respective radio signals each of which over alternate periods, has a constant frequency different from that of the other signal and a frequency which repetitively increases and decreases in a respective frequency sweep extending over several of the periods, the frequencies of increase and decrease being the same for the two signals, while simultaneously the phase displacement between the sweeps is slowly and cyclically altered in such a manner that the instantaneous frequency difference between the transmitted signals has at any instant a predetermined value, and a radio receiver including two superheterodyne radio receiving channels each receiving one of the signals, a mixer causing the signals to beat with one another to produce a heterodyne frequency, and an indicator for indicating any frequency difference in the heterodyne frequency produced in successive periods, the system operating so that the number of discrete signals produced by the indicator from a reference instant until the frequency difference is substantially zero provides an indication of the difference in the times of travel of the two signals and thereby of the position line.

9. A radio navigational system according to claim 7 in which the indicator is an electroacoustic transducer operating in response to the heterodyne frequency.

10. A radio navigational system acocrding to claim 7 or 8 in which:—

(a) the phase displacement is altered by an equal frequency step in each of the said constant frequency periods;

(b) at least one of the constant frequencies alternates between two different constant frequencies in successive said constant frequency periods such that in these periods the heterodyne frequency alternates between two different frequencies separated by a frequency difference equal to the frequency step in the heterodyne frequency occurring in the other periods as a result of (a); and

(c) the receiver includes a second indicator which indicates the proportion of the heterodyne frequency step occurring when the frequency difference is substantially zero.

11. A radio navigational system for establishing a position line, substantially as described with reference to and as illustrated in Figure 3*a* of the accompanying drawings or as modified by Figures 3*b* and 3*c*.

12. In or for a radio navigational system as claimed in Claim 1, a navigational instrument comprising two radio receiving channels, tuned to receive the respective basic frequencies together with their increased frequencies, a mixer for causing signals from the channels to beat with one another to produce a heterodyne frequency, and an indicator for providing an indication of the value of the heterodyne frequency.

13. In or for a radio navigational system as claimed in any of Claims 1 to 11, a navigational instrument comprising two superheterodyne radio receiving channels, an adjustable delay arrangement for adjustably delaying the signal from one of the channels, a mixer for causing the signal from

the delay arrangement and from the other channel to beat with one another to produce a heterodyne frequency, and an indicating arrangement having a first indicator for indicating whether the heterodyne frequency remains constant and a second indicator controlled by the delay arrangement for providing an indication of the delay when the heterodyne frequency remains constant.

14. A navigational instrument according to claim 13 in which the first indicator is an electroacoustic transducer operating in response to the heterodyne frequency.

15. A navigational instrument according to claim 13 or 14 in which the adjustable delay arrangement includes an ultrasonic delay line.

16. In or for a radio navigational system as claimed in any of claims 1 to 11, a navigational instrument substantially as described with reference to and as illustrated in Figure 2*a* of the accompanying drawings.

17. In or for a radio navigational system as claimed in any of claims 1 to 11, a navigational instrument comprising two superheterodyne radio receiving channels, a mixer for causing the signals from the channels to beat with one another to produce a heterodyne frequency, and an indicator for indicating any frequency change in the heterodyne frequency.

18. A navigational instrument according to claim 17 in which the indicator is an electroacoustic transducer.

19. A navigational instrument according to claim 17 or 18 including a second indicator capable of indicating smaller frequency changes in the heterodyne frequency than the first indicator.

20. A navigational instrument according to claim 19 in which the second indicator is a meter.

21. In or for a radio navigational system, as claimed in any of claims 1 to 11, a navigational instrument substantially as described with reference to and as illustrated in Figures 2*a* and 2*b*, or Figure 3*b* or Figure 3*c* of the accompanying drawings.

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1272745 COMPLETE SPECIFICATION

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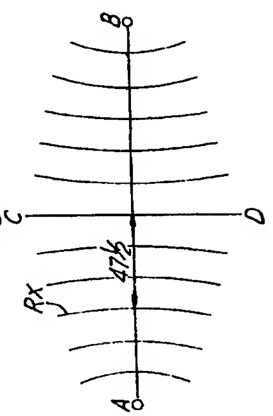

Fig. 1a.

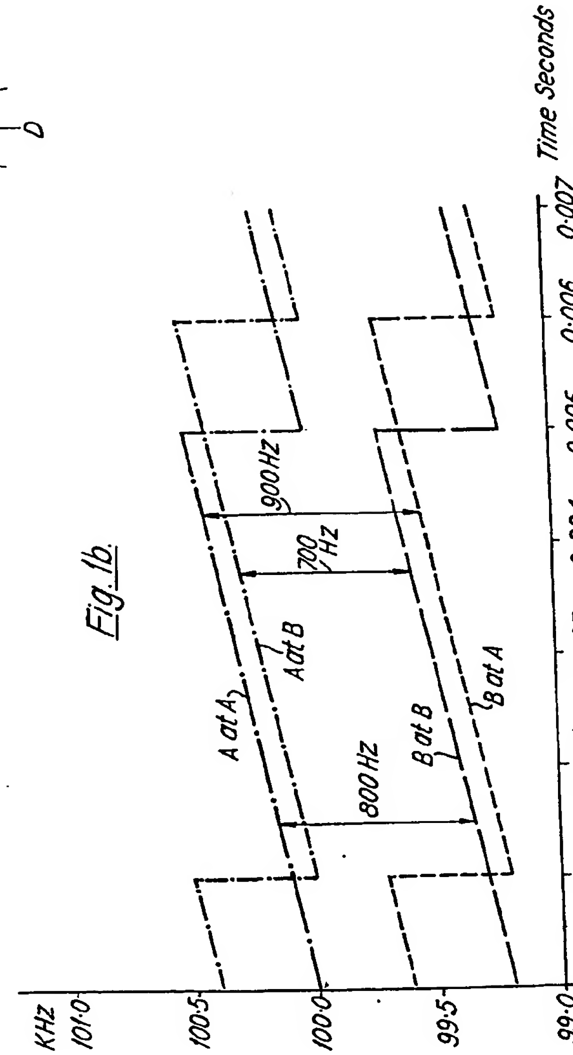

Fig. 1b.

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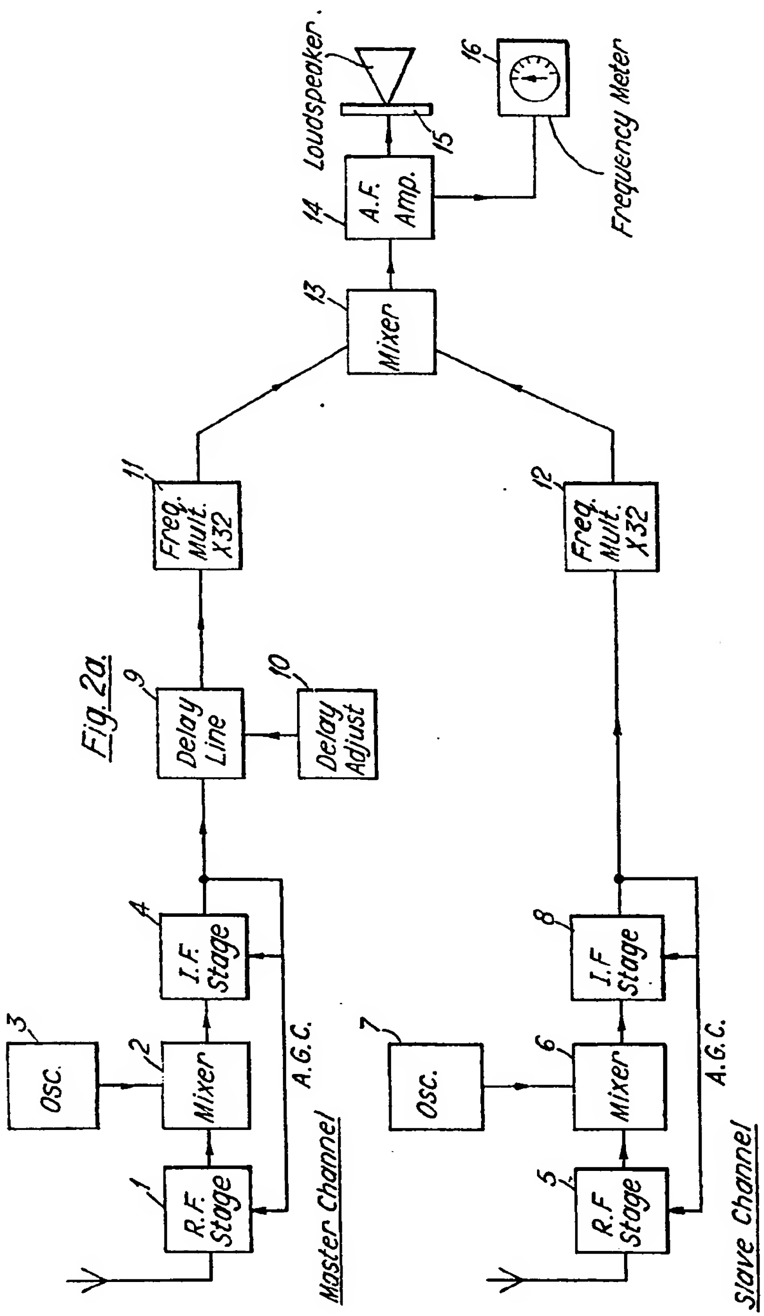
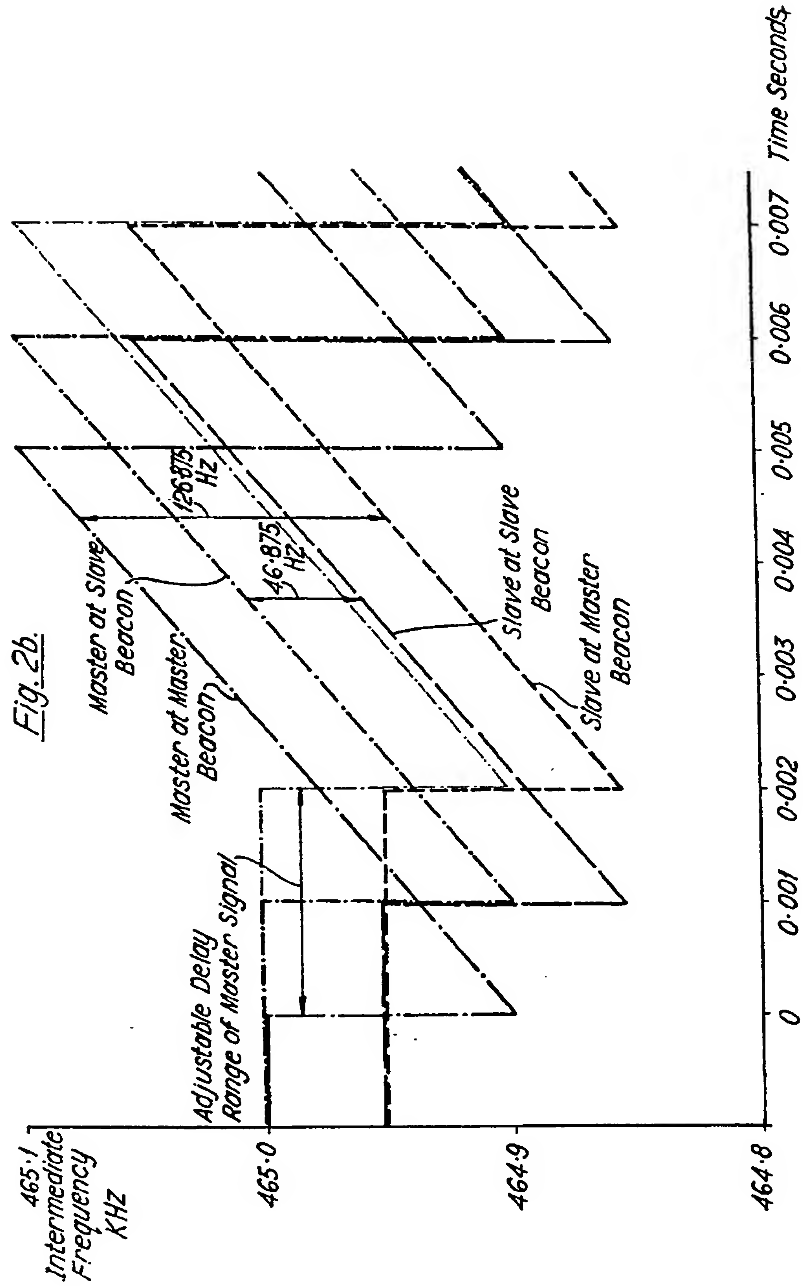


Fig. 2a.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465·0
464·9
464·8
Time Seconds
0
0·001
0·002
0·003
0·004
0·005
0·006
0·007
Adjustable Delay Range of Master Signal
Master at Master Beacon
Master at Slave Beacon
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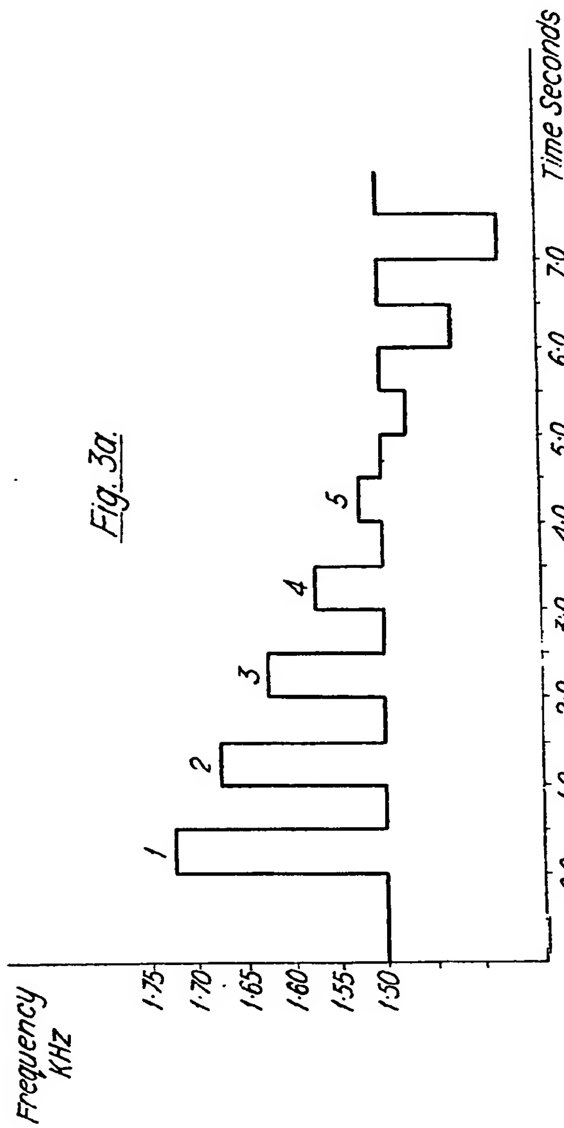
46·875 Hz
Slave at Slave Beacon
Slave at Master Beacon

Fig. 2b.


Frequency KHz
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1·70
1·65
1·60
1·55
1·50
0·0
1·0
2·0
3·0
4·0
5·0
6·0
7·0
Time Seconds
1
2
3
4
5

Fig. 3a.

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Sheet 5

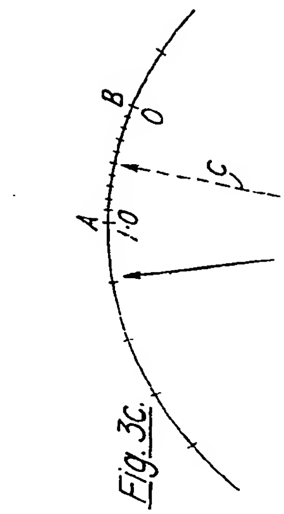

Fig. 3c.

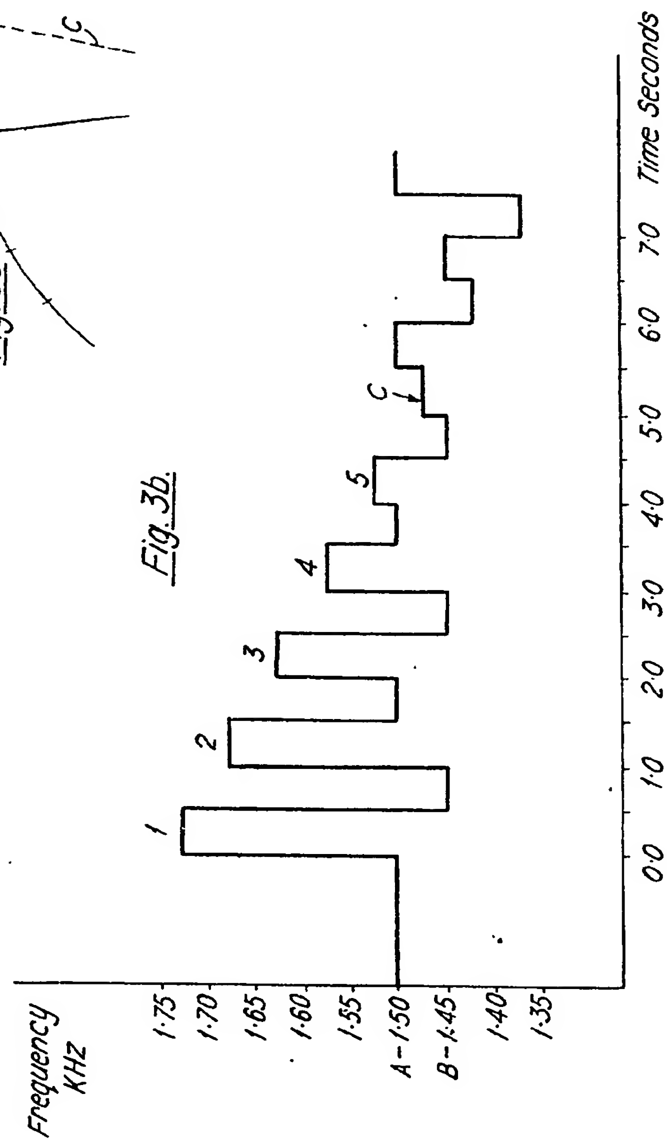

Fig. 3b.